# Catching the Big Fish: A 4E-Cognition Approach to Creativity in STEAM Education

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**> Context** • The 4E approach proposes an alternative framework to understanding cognition and learning. However, its application to the study of creativity from new educational approaches such as STEAM is incipient. **> Problem** • How can the 4E approach that fosters creativity be implemented in STEAM education, through participation in technology-mediated learning ecosystems? **> Method** • Through face-to-face ethnographic participant observation, we observe students engaging in creative activities suggested by our theoretical approach. We use these observations to illustrate our theoretical approach. **> Results** • Our examples show the many possibilities to encourage creativity by participating in STEAM educational environments that promote design and prototyping with technologies. We highlight collaborative work, disciplinary integration and learning by doing, characteristics of the STEAM approach, which favor the implementation of the 4E approach. **> Implications** • The STEAM approach encourages creativity and learning that gives primacy to training processes over final products, so it is consistent with the 4E approach. **> Constructivist content** • We adhere to the 4E approach to cognition: embodied, enacted, embedded and extended.
**> Key words** • **21st century skills, 4E approach, creativity, STEAM education.**

## Introduction

« 1 » Creativity is considered one of the essential skills for the future workforce (Frey & Osborne 2017)[1] and crucial to face the challenges proposed by the sustainable development goals. This justifies the impetuous desire of the United Nation's 2030 education agenda[2] to promote initiatives that highlight the fundamental role of creativity in educational processes (Reimers & Chung 2019). To broaden the understanding of the phenomenon of creativity in the light of new contemporary approaches to cognition, we have taken the metaphor of the filmmaker David Lynch (2006), who relates consciousness to a great ocean in which fish flow as ideas of different sizes and the deeper one goes, the more chances of "catching the big fish." Applying this metaphor, our target article can be seen as an invitation to metaphorically immerse oneself in the idea of creativity as "catching the big fish." In our reading, this metaphor refreshes the conceptual inertia with which creativity has been studied within cognitivism, and adheres to contemporary notions of cognition that highlight dynamic, embodied and emerging facets. An example of this is the notion of optimal grasp as the attempt to objectify emergent understanding (Gibson 1979; Rietveld & Kiverstein 2014; Abrahamson & Sánchez-García 2016).

« 2 » One of the contemporary approaches that provide alternative pathways to traditional cognitivism that has encapsulated the notion of creativity in processes and products is the 4E (embodied, enacted, embedded and extended) approach. The relationship between creativity and the 4E approach is incipient, as exemplified in experimental studies (Malinin 2019; Baber, Chemero & Hall 2019; Frith, Miller & Loprinzi 2020) and studies on musical creativity (Schiavio & van der Schyff 2018; van der Schyff et al. 2018). A paradigm shift is urgently needed in the study of creativity that can integrate embodied and interactional approaches for a deep understanding of this phenomenon (Kupers et al. 2019). If we explore the tradition of studies on creativity, we show diverse perspectives, with the ideas of final products and internal mental processes being the most investigated, see problem-solving ability (Guilford 1967), divergent thinking (Torrance 1972), creative intelligence (Sternberg & Grigorenko 2001), lateral thinking (Gardner 1994), and the Four C Model of Creativity from mini-c to little-c to Pro-c to Big-C (Kaufman & Beghetto 2009).

1| See also the 2018 OECD position paper "The future of education and skills: Education 2030." http://www.oecd.org/education/2030/oecd-education-2030-position-paper.pdf

2| "Transforming our world: The 2030 agenda for sustainable development," United Nations 2015. The 2030 educational agenda declares the need to incorporate the 17 sustainable development goals into educational practices that contribute to creating a society based on individual, social and planetary well-being. https://documents-dds-ny.un.org/doc/UNDOC/GEN/N15/291/89/PDF/N1529189.pdf



https://constructivist.info/18/2/295.videla

« 3 » From our theoretical lens, we want to divert attention from asking what happens in the head or in the world that makes people creative, so we prefer to take an alternative path to traditional notions of end products and internal mental processes. Rather, we invite creativity from the 4E approach to be thought of as a skillful experience[3] embedded in context and arising from the distributed engagement of perception (Hutchins 1995; Kalaydjian et al. 2022; Rietveld 2012; Schiavo & van der Schyff 2018). In order for our ideas to have a fertile ground to take hold of, we adhere to the STEAM (Science, Technology, Engineering, Art and Math) educational approach, which presents an auspicious field for the development of creativity in 21st century education (Liu et al. 2021).

« 4 » The STEAM educational approach provides sensorimotor environments rich in disciplinary integration and the use of creative and electronics technologies, contributing to solving the complex challenges of societies, preparing them for Society 5.0 (Shiroishi et al. 2018). In the course of the article, we will use the notion of "sensorimotor environment" to allude to the contingent relationships that shape stage skillful performance in response to the sense of situation of sensorimotor engagement with artifacts and people (Merleau-Ponty 1962; Dreyfus 2002; Rietveld & Brouwers 2017). STEAM is an attractive approach for educational organizations that need to train creative people who can drive local and global changes hand in hand with technology to improve people's quality of life. The relationship that we glimpse between STEAM and the 4E approach is framed in the systemic curriculum (Jacobson & Wilensky 2022), learning by doing (Dewey 1934), sensorimotor engagement between people and artifacts (Di Paolo, Buhrmann & Barandiaran 2017), learning based on projects (Kilpatrick 1918), and design thinking (Brown 2009).

« 5 » We adopt the 4E approach, framed as a non-representationalist and anti-realist approach. The STEAM approach provides sensorimotor environments that are sensitive to the bodily possibilities derived from each person's experience. Hence, we abdicate any attempt to understand creativity through contentious representations. We are interested in understanding creativity from embodied, embedded and distributed experience by participating in STEAM projects that offer multiple social and technological possibilities for the deployment of skillful practices.

« 6 » The metaphorical relationship between creativity and catching the big fish consists of thinking about projects as a bait. In this way, the creative experience that we describe, which requires building an artifact, involves the collaborative and embodied deployment of multiple ways of thinking that emerge from sensorimotor engagement and take shape with different types of materiality. There is no design or intention in mind, only actions that make intentions in the act of perceiving and acting. Therefore, creativity grows with practice in the form of a distributed experience that is nourished by previous actions that make opaque or invisible aspects of previous prototypes clear to the present (Videla-Reyes et al. 2023). From here also, we conceive the link with the 4E approach, which goes beyond understanding creativity in processes with intentions in the form of mental representations and products encapsulated in their design restrictions.

« 7 » Based on the previous ideas and inspired by Lynch's (2006) metaphor, we consider creativity as the emergence of a deep experience that comes about during sensorimotor engagement with artifacts and interaction with other people, which opens unprecedented possibilities of catching emerging understanding and reconfigures skillful performance in challenging tasks (Ingold 2010; Glăveanu 2014a; Ihde & Malafouris 2019; Malinin 2019). Motivated to contribute to the understanding of creativity from the 4E approach in the light of STEAM education, we offer a conceptual analysis supported by selected cases. Our article may be of great interest to open and broaden discussion among educational researchers, cognitive scientists, and school educators about the potential development of creativity in STEAM environments that generate multiple possibilities for participation and sensorimotor engagement with technologies.

## A cognitive paradigm shift for 21st century education

« 8 » The revival of philosophical debates about the mind/body problem to understand the functioning of cognition has attracted not only cognitive scientists, philosophers of mind, neuroscientists, and psychologists, but also anthropologists, archeologists and educators (Shapiro & Stolz 2019). Indeed, we have witnessed heated and illuminating philosophical and empirical debates in favor of enactive and embodied perspectives that represent an epistemological odyssey necessary to anchor foundations against dualistic and cognitivist notions (Vörös, Froese & Riegler 2016). Historically, the dualistic tradition has had an important impact on the psychology of learning and education, relegating the body and the environment to the background (Radford et al. 2017). In the same way, the prevailing cognitivism, driven by the idea of revealing an objective world independent of the agency of the human being, has separated brain and body processes, confining cognition to internal and external representations that oppose the idea of a cognitive system immanent to relationships and transformations.

« 9 » In opposition to classical cognitivism that has focused on the metaphor of the mind as a computer, the 4E approach has relieved the notion of cognitive system of the idea of information processing (Newen, De Bruin & Gallagher 2018). It implies a conceptual reconfiguration of how we understand cognition beyond a computationalist logic based on internal and external physical mental representations. Rather, it underlines the continuum of the mind and life to inform the richness of cognition and learning from sensorimotor engagement, through specialized embodied practices (Thompson 2007). In this sense, cerebral and extracranial processes are mutually specified, thus enabling cognition in behavioral, social, political, and cultural contexts (Bateson 1972).

3| Our theoretical proposal of creativity is based on a skillful experience, that is, a way of thinking through making that illuminates opaque facets previously invisible (Ingold 2010). This is in contrast to the concept of skill understood as a "particular application of skill" (Pye 1964: 55) or distinctions between declarative and procedural knowledge (Masson 1990).

« 10 » The 4E approach, enacted (Varela, Thompson & Rosch 1991), embodied (Johnson 1987), embedded (Hutchins 1995), and extended (Clark & Chalmers 1998) contributes to favoring an account of cognition in which the perceptuomotor structure of the organism is dynamically coupled and distributed in the environment. Although each of the Es presents a different perspective on the nature of cognition, particularly extended cognition, it is possible to show more common than different aspects. This is because they share the idea that cognition is manifested through practical and situational knowledge, shaped by the dynamic reorganization of perception-action loops. These ideas positively impact education in the 21st century, since they allow a broadening of the understanding of teaching and learning from a revitalization of action and perception, considering inspiring perspectives of the 20th century such as Friedrich Fröbel's (2005) pedagogy of play and activity, María Montessori's (1967) pedagogy of the sensorial materials, John Dewey's (1944) learning based on experience, Jean Piaget's (1971) genetic epistemology, Lev Vygotsky's (1978) sociocultural mediation, Seymour Papert's (1980) constructionism and educational technology, Jerome Bruner's (1962) learning by discovery, and Ernst von Glasersfeld's (1995) radical constructivism.[4]

## The 4E approach: Embodied, enacted, embedded and extended

« 11 » Embodied cognition rejects the conception that behind ideas there are formal mechanisms or logical rules that drive them. Rather, it proposes that sensorimotor engagement is the foundation of all activity (Shapiro 2011). From this perspective, concepts and images are not static brain structures but emergent sense-making procedures shaped by body schemas (Glenberg 2008). Embodiment alludes to the body as a sensorimotor structure based on the premise that brain and body are evolving together, and thus are intrinsically coupled through experience (Lakoff & Johnson 1999). Take for example, George Lakoff and Rafael Núñez's (2000) anti-realist and anti-idealist claim that mathematical ideas cannot be conceived of outside of everyday life, since our concepts are structured by what we perceive as we move and relate to artifacts and people. Cognition is constituted in various modalities, which allow us to operate in the world through sensation, perception, imagination, and through sensorimotor engagement with technological artifacts, and extended practices of coexistence and adaptation (Gallagher 2017).

« 12 » The enactive approach is inspired by the idea of autopoiesis, Mark Johnson's (1987) embodied cognition approach, Maurice Merleau-Ponty's (1962) body phenomenology, and Scott Kelso's (1992) neuroscientific evidence of dynamic systems. Francisco Varela, Evan Thompson and Eleanor Rosch (1991) proposed the concept of enaction referring to "cognition in action: a history of structural couplings that produces a world by actively participating in it" (ibid: 207). Enactivism is based on the view that cognitive systems are self-referential agents that define their own systemic identities and represent their own inherently significant environments through adaptive processes of meaning creation (Froese & Di Paolo 2011). The initial enactivist approach has branched out into several varieties of enactivism: autopoietic (Varela, Thompson & Rosch 1991), sensorimotor (Di Paolo, Buhrmann & Barandiaran 2017), and radical (Hutto & Myin 2013). What they have in common is that individuals interact through embodied interactions with environmental resources, the perception of which depends ultimately on their sensorimotor capacities, and as they participate socially, they are transformed into ways of thinking with symbols (Hutto, Kirchhoff & Abrahamson 2015).

« 13 » Bodily knowledge is often embedded (Haugeland 1998), distributed (Hutchins 1995), and materially engaged (Malafouris 2013) in contexts where it is skillfully deployed. Since the embodied mind cannot be conceived of in isolation from its environment, authors such as Michael Tomasello 2008; Harry Heft (2013) and Michael Turvey (2019) claimed it was embedded in a "socio-cultural environment." In addition, the imposed dualisms of nature and culture, or mind and matter, are innocuous, due to the relational ontology that is at the base of sensorimotor engagement and that opens up new varieties of material forms (Malafouris 2014). The cognitive agent, through distributed cognition, configures new ways of perceiving that guide action for the agent, allowing skillful and effective deployment in enculturated environments through material anchors (Hutchins 2010). Embedding cognition in environmental resources, such as tools and artifacts of material culture, amplifies and organized the trend toward optimal and adaptive control of the situation (Bruineberg & Rietveld 2014).This "optimal grip" between the organism and the environment accounts for a constant flow of skillful activity in response to the sense of the situation shown in the sophistication of practice that makes relevant particular characteristics, which tends to reduce the complexity of the activity.

« 14 » Extended cognition emphasizes the possibility that the cognitive system extends beyond its bodily structure to external entities (Clark & Chalmers 1998). The extension of cognitive agents to external artifacts depends on the processes or mechanisms that constitute a functional system (Menary 2010). In some cases, the cognitive system extended to elements outside the body surface must function in an equivalent manner to the original cognitive function in order to be considered to perform cognitive work (Wheeler 2010). Menary (2018) argued there are weak and strong versions of functionalism depending on the type of activity to be carried out. The weak version refers to the temporary use of an artifact in specific situations. On the other hand, the version of strong functionalism implies the integration or grafting of an external artifact that becomes indispensable for the execu-

4| The relationship between radical constructivism and the 4E approach is framed in the central role of the observer, which alludes to the epistemological corollary "reality is neither rejected nor confirmed, it must be considered irrelevant" (Riegler 2001: 4). Inspired by von Glasersfeld (1988), experience is thus a form of self-reference, in the sense that there is no objective reality to discover, only the organization of an experiential world. Radical constructivism is in tune with the 4E approach in general and enactivism in particular, as it considers cognition to be the embodied ability that shapes the world and to be inseparable from sensorimotor capacities.

tion of essential routines for the adaptive performance of the agent, as is the case for a cochlear implant to regulate sound waves, if the agent is deaf.

« 15 » The 4E approach provides a framework for understanding the systemic, embodied, and situated dynamics of educational processes. Learning scientists who adhere to the 4E approach are uncovering the cognitive structure of deeper conceptual understanding, as well as the principles that constitute learning most meaningful to living in a 21st century global society (Macrine & Fugate 2022). This new society requires decision-making skills that contribute to solving complex problems, one of the most relevant being creativity.

## Approaches to the study of creativity

« 16 » Creativity has become one of the fundamental skills to be developed in the 21st century, which is why different paradigms of creativity have become attractive to researchers in education, such as studies on final products (Guilford 1967) and thought processes (Torrance 1972; Sternberg & Lubart 1999; Kaufman & Baer 2005). Much of the research on creativity has addressed the challenging mission of understanding how cognitive agents deploy new ways of thinking and doing in socio-material environments. Our contribution to the existing evidence seeks to understand the flow of actions of the creative experience that involves capturing the idea through the creation of prototypes for the making of an artifact within the framework of a STEAM sensorimotor environment. In the example we will describe in more detail below, of creating a buoy, we describe the iterative flow of actions from 2D design, 3D modelling, CNC (computer numerical control) router manufacturing and thermoforming during the creative experience. Unlike traditional creativity studies focused on thought processes and thought products, we focus on thinking through making and learning by doing, which are in tune with the 4E approach.

« 17 » In the field of domains and personal products, James Kaufman and Ronald Beghetto (2009) suggested that we consider creativity a continuum between little-c, understood as everyday creativity, and Big-C, understood as eminent and cultivated creativity. The continuum accounts for the progress and expansion of skills that can range from the invention of devices made by children at school called mini-c, to higher levels of genius corresponding to Big-C. The emphasis of the creative person focused on problem solving has had opponents, such as Teresa Amabile (1996), who have focused on how social and environmental factors can influence creative processes. Similarly, Vlad Glăveanu (2014b) has proposed that creativity is a process that emerges from the continuous interactions between the person and the environment. Inspired by the work of Edwin Hutchins (1995), Juliette Kalaydjian et al. (2022) have presented a distributed model of creativity that highlights the codependent relationship between cognition and the socio-cultural environment.

« 18 » Product and process research on creativity generally agrees that creativity involves the combination of originality and appropriateness to the task (Kaufman & Sternberg 2019). Lev Vygotsky's (1971) first works on the psychology of art, in which he examines imagination and creativity in childhood, considered the historical-cultural perspective to understand the symbols and tools used when producing new cultural artifacts (Dafermos 2018). In this way, the centralization of the creative process in the person, as pointed out (Gardner 1994), has been blurred with the evidence from cultural psychology in which the creator as well as the creation are considered inseparable from the environment woven by social relations and accumulated cultural artifacts (Glăveanu & Beghetto 2017). Our proposal is in tune with Mitchel Resnick's (2017) four Ps – Project, Passion, Peers and Play – suggesting that creativity is cultivated through learning by doing with different materials and technologies in project contexts.

« 19 » The relationship between 4E cognition and creativity has been explored by different studies, inspired by distributed and emergent approaches (Csikszentmihalyi 1988). Among these studies, the one that stands out is by Dylan van der Schyff et al. (2018), who argue that creativity in the musical field emerges from patterns of embodied and embedded adaptive interaction that occur between multiple agents, as well as the extended sensorimotor environment implied by the use of instruments. Likewise, studies on creative thinking and 4E from dance show the potential that dance has to favor the coordination and embodiment of concepts or problems of nature that are staged, through theatrical projects that involve experience (Purvis 2021). Other studies have focused on the moments in which creativity emerges during distributed and collaborative agency between the human and the material (Ross & Vallée-Tourangeau 2021). Our proposal from the 4E approach is to describe the creative experience in dynamic sensorimotor environments such as STEAM, where the sensorimotor engagement with different materials provides different modes of embodiment and embedding of cognitive agency.

## STEAM Education: Dynamic sensorimotor environment

« 20 » The United Nation's 2030 educational agenda has proposed dispensing with traditional educational processes that preserve a monolithic curriculum, competition, and automation of procedures. The STEAM educational approach is presented as an auspicious field for new forms of education that incorporate the sustainable development goals of the UN and the skills of the 21st century, such as collaborative work, creativity, intellectual openness, computational thinking, and critical thinking among others (Reimers & Chung 2019). STEAM is conceived as an educational approach with sociopolitical objectives that promote sustainable education based on lived problems, interdisciplinarity and learning by doing with immersive and creative technologies (Videla, Aguayo & Veloz 2021). Unlike the STEM approach that promotes gender inclusion, the use of technologies and a strong commitment to citizenship, STEAM amplifies educational opportunities by incorporating art, as it highlights design, creativity and new aspects, such as creative electronics and digital immersion (Herro et al. 2022).

« 21 » STEAM provides a framework for action to catalyze the educational objectives of the Organization for Economic Cooperation and Development (OECD) that refer to individual, social and planetary well-being, through disruptive innovation strategies such as design thinking. STEAM is used in different educational contexts; sometimes it is necessary to implement active methodologies such as project-based learning (PBL). This type of methodology is based on the definition of a purpose and a challenge that students must solve by investigating, designing and prototyping by themselves, since the teacher is only a facilitator. PBL is an effective methodology to improve the affectivity, collaboration and academic performance of students (Quigley et al. 2020). This is because, in PBL, students first become aware of lived problems, and then develop more complex skills during the process of designing and prototyping different solutions.

« 22 » STEAM and PBL facilitate the generation of learning ecosystems that involve sensorimotor ways of participating with analog and digital technologies. The rise of digital fabrication, 3D modeling, electronics and robotics, and the immersive technologies of augmented reality, virtual reality and extended reality, provide new digital means for the development of creative skills in the K-12 curriculum (Kelly & Cunningham 2019). The importance of creative technologies within the framework of STEAM lies in the possibility of thinking about environmental problems, to later seek solutions in a systemic and embodied way through design, alternative ways of using electronics, sensorization and digital manufacturing.

« 23 » The evidence between STEAM and creativity shows that there is a strong research emphasis on creativity in the individual, based on thought processes and individual problem solving (Aguilera & Ortiz-Revilla 2021). On the other hand, it has been shown that students become more creative in engineering-project environments that encourage motivation and learning by doing in Maker activities that involve technology and sensorization (Jia, Zhou & Zheng 2021). This type of technology encourages students to play with tools intuitively, increasing their motivation and commitment to the activity, expanding new ways of learning and innovative solutions (Nikolopoulou 2018).

## Catching the big fish of creativity from STEAM and the 4E approach

« 24 » In our creativity proposal, we consider the previously presented contributions linked to processes and products to be relevant, however, we share much more with the 4E approach perspectives that adhere to the idea of an emerging phenomenon, embodied and embedded in socio-material environments. In this article, we want to review the phenomenon of creativity in light of the STEAM educational approach, which can be understood as an environment rich in sensorimotor possibilities, which, through projects, encourages the design and prototyping of technological artifacts to solve problems. The way to do this is through learning by doing. Unlike traditional models of creativity with STEAM that focus on the creative person and the final products, we propose to understand creativity by reading it forward as argued by Tim Ingold (2014). This means thinking about the creativity inherent in practice and paying attention to the development of contingent relationships in which knowledge grows from the crucible of our skillful engagements with different kinds of technologies and materials (Ingold 2013).

« 25 » Inspired by Lynch's (2006) metaphor of catching the big fish, we posit creativity as a deep experience of or through the material, which opens up unprecedented possibilities during the flow of actions, and posit that from the accumulation of ineffable sensations that people experience immersed in environments rich in sensorimotor possibilities, it is distributed and reoriented in the course of actions, reconfiguring skillful performance in tasks that become challenging (Merleau-Ponty 1962; Ingold 2010; Glăveanu 2012; Malafouris 2014; Malinin 2016). In this sense, our metaphor of creativity illuminates those facets of the experience that occur in deep immersion through the materials, and that suddenly bring, in the course of actions, new ways of perceiving that performatively enrich a prototype, work or solution. In our case, the facets are 2D design, 3D modelling, manufacturing with a CNC router and molding with thermoforming machines. Since the project is analogous to a bait, when the big fish catches it, all the triggering actions flow in favor of the emergent purposes. From our theoretical lens, the process of catching the big fish is through the spontaneous emergence of attentional anchors that increase concentration and therefore, the working memory that contributes to the amplification of the experience (Hutto, Kirchhoff & Abrahamson 2015).

« 26 » STEAM learning environments within the framework of the 4E approach provide sensorimotor scaffolding that does not follow prescribed guidelines, but rather paths of uncertainty where cognition is always oriented towards an absent structure (Varela, Thompson & Rosch 1991). This makes them an inexhaustible field for the deployment of creative experiences. This point is essential to understand creativity beyond an internal process or final products: rather than reading creativity backwards, it must be read in its constitutive and dynamic ontology, "as an experience moving forward, in which ideas […] have to crystallize through the flow of actions" (Ingold 2014: 6). Catching or grasping creativity relieves the paradox of grasping the elusiveness of cognition, but as with the material, we try to at least approach it metaphorically.

« 27 » In our anecdotal observations that we make in the educational contexts in which we work, we would like to highlight the role of the creative experiences that design-engineering students display in the Emerging Interfaces Center of the Adolfo Ibáñez University. In this laboratory, students experience creativity in the dynamic flow of design, prototyping and testing of different artifacts that can contribute to a solution to a problem, or enjoy an aesthetic experience. The laboratory is equipped with tools for digital design, CNC prototyping, digital manufacturing on 3D printers, and different electronic materials such as arduinos and sensors. A large proportion of these tools serve to propel scaffolding for creative experiences, since students can embody and extend their thoughts through different materials and technologies.

« 28 » With the aim of supporting and illustrating our theoretical ideas about the creative experience, we present below one specific example of the design and prototyping situations carried out over the years in the Emerging Interfaces Center. We discuss, from our theoretical perspective, particularly the dynamics of creative experience observed in sensorimotor environments of STEAM education. In the example below, we will describe the flow of actions that the creation of artifacts entails from the identification of the problem, ideation, design and prototyping. In each case, we show how creativity can be grasped through dynamic coordination and progressive sensoriomotor coupling in which perception is distributed in materiality.

## An example of creativity in STEAM educational environments

« 29 » The following case of STEAM education has been developed in the Emerging Interfaces Center of the Design Lab of the Adolfo Ibáñez University, in Chile. Using a PBL methodology, inspired by the 4E approach and the 3Hs that were developed from John Dewey's pragmatism (head-heart-hand),[5] some principles or steps were adopted in which an art project was produced, encouraging work with electronics and digital technologies. The proposed creation methodology uses the 3Hs, since they are inseparable in the flow of the creative experience, the head, heart and hands connection. Think, for example, how an electronic circuit is assembled, how the parts can be manufactured, the relationships between electricity and magic, and how to understand a project in a social context that makes an impact in the face of the challenges of the 2030 educational agenda.

« 30 » The STEAM approach, through this eclectic project-based learning methodology, encourages curiosity and commitment to the project that is generated from the students' own interests and experience, promotes autonomy, collaborative work and learning through sensorimotor engagement with different types of technologies and materials. This methodology consists of a four-step structure: observe/document/do-reflect/show. In this flow of actions, students embed themselves in their environment, pose questions, reorient their perception, systematize their ideas, extend their thinking through different technologies such as 3D modeling, CNC prototyping, the use of sensors, arduinos and the internet of things.

« 31 » Next, and through an ethnographic anecdotal description, the case of the design and manufacture of a buoy to measure fresh water in southern Chile is presented, based on the request of the Nawi team (https://www.nawi.cl), which is an organization based on co-design of environmental monitoring systems, involving various citizens as participants in solutions to environmental problems in their territory. In the phase of observing and empathizing with nature, the design-engineering students, together with their teacher, took on the existing problems in communities near rivers, lakes and wetlands in Chile, which alludes to the scarce knowledge of the quality of the water. In order to find a solution to this problem, the students began to work on this challenge.

« 32 » During the phase of observation, students pose various questions as they learn to perceive. In other words, they embed themselves in a place and let that place, including its people, nature and everything that makes it up, impregnate them, through the senses, with everything possible. In this case, they deal with the problem of designing a buoy-style floating structure that can house electronic boards in its structure that can integrate remote sensing to measure water quality. The challenge urges students to unfold their intuitions about the shape that the structure should take; for this they need to embody and extend their ideas in physical or material media that they have at hand, such as the napkin that appears in Figure 1a. Here, it is possible to trace the first steps of the flow of the experience through the action of designing a 2D sketch.

« 33 » In the document phase, students take all the previous observations that are documented in any medium, be it notebooks, photographs, videos, sound or text. The objective of this step is to continually visit what they were doing in previous activities, so they can expand the sensorimotor engagement and material possibilities of the design. This documentation must be uploaded to an electronic medium such as a web page, blog or other digital repository, so that it is available to others. This allows them not to lose any intuition or idea, no matter how vague, in the course of their actions, so that later they will be able to produce much more powerful prototypes. In Figure 1b, it is possible to see the sketch made on a sheet of paper of the design of the structure of a buoy documented. Here the students explore graphically, through hand-eye coordination extended on a paper surface, the most appropriate way to house the electronic remote-sensing device inside. The design action on the sheet of paper, much more detailed than the sketch on the napkin, illuminates new ways of perceiving and conceiving the prototype. This is due to new social and material possibilities that have resulted from the exploration and investigation of the electronic component.

« 34 » In the Do/Reflect phase, students have tangible materials, tools and technological machinery, however, they choose them according to the scale of the project. In this phase, the preliminary intuitions and the sketches on the napkin and paper begin to be reconstructed through distributed perception in different types of technologies, such as 3D-modelling software. Intuitive and technical 2D design skills displayed on paper and pencil are reconfigured by co-developing computational design skills that require other forms of engagement involving visuospatial reasoning, isometric transformations, and programming. Added to the above, collaborative work among students at this stage is essential, since they must reconcile perspectives and be able to co-inhabit a shared

5| The notion of 3Hs has roots in Johann Heinrich Pestalozzi's holistic approach to teaching (Brühlmeier 2010). It has been addressed by Julie Singleton (2015) within the framework of a transformative education model inspired by the pragmatist ideas of John Dewey (1976) and the ecoliteracy of David Orr (1992) to generate a sustainable pedagogy. In our study, we complement the ideas of Singleton (2015) on Head, Heart and Hand, from the synergy of ideas of John Dewey (1934, 2005) on how experience is not just stuff presented to or witnessed by consciousness; rather, experience is activity, engagement with life. This is an experience that can change a person's relationship with the world, a new way of seeing, a new way of being in the world that is transformative. These ideas resonate with the 4E approach, since they share the ontological corollary that practice is not merely something that we do as a means to an end, but is constitutive of cognition as experience (McKinney, Steffensen & Chemero 2022) and kinesthetic knowledge (Penny 2022).

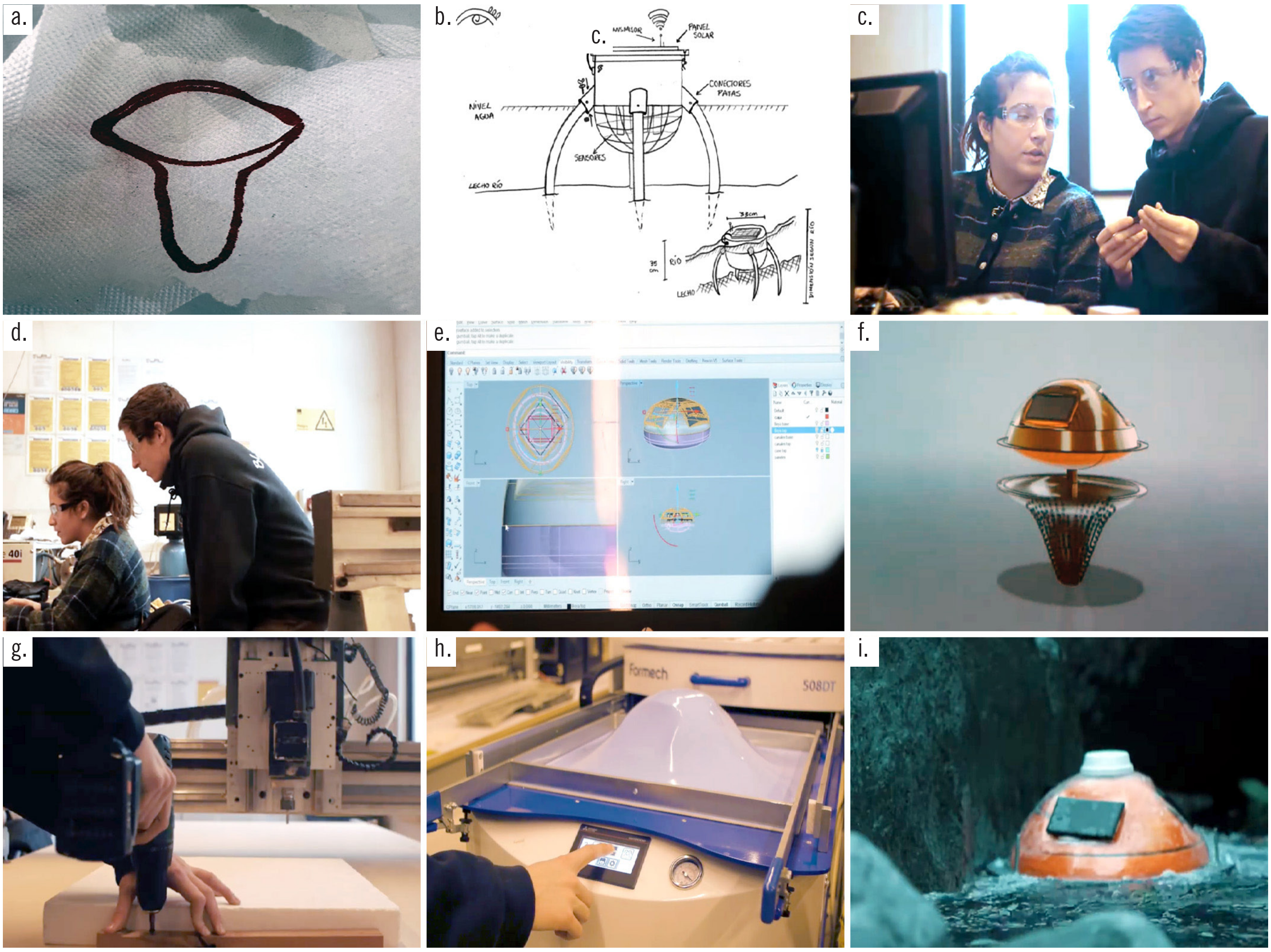


**Figure 1** • Screenshots from an educational STEAM in which a prototype is designed and manufactured to measure the water quality and contribute to environmental education. Here is part of the flow of actions of the creative experience: (a) Drawing on a napkin. (b) Manual sketch of the prototype. (c) Reconciliation of perspectives. (d) Preliminary co-design of the digital prototype. (e) Roaming of the digital prototype. (f) Final co-design of the digital prototype. (g) Prototyping in CNC router. (h) Manufacture in thermoforming. (i) Implemented product.



experience of creativity. Here, the students reconfigure their ways of perceiving together, they co-create meaning to the extent that the possibilities offered by the emerging field of action allow them to grasp a minimal and viable prototype after a number of iterations, as can be seen in Figures 1b, 1c, and 1d.

« 35 » This Do/Reflect phase is essential in the creative experience, since students, after countless iterations and different ways of embodying their ideas, manage to reconcile the ad-hoc prototype in the digital design that allows them to give a partial solution to the problem. What is interesting is that this incessant search for design implies a tendency towards optimal balance of the sensorimotor system in order to grasp the ideal prototype. This tendency can be observed in the intensification of skillful activity in response to the demands of the situation. When students reach such a level of creative immersion in design, they are able to give a perceptual solution that allows them to partially catch the creativity. This is due to the spontaneous emergence of attentional anchors, in which students stabilize their ideas as the practice becomes increasingly skillful, thus opening up new possibilities of understanding. In the case of computational design with 3D modelling, the continuous reconfiguration of the shape of the artifact depends on the optimal physical conditions for storing the electronic board. The more they understand the scientific, technological and engineering variables involved in the requirement, the more advanced design skills that involve art appear in the display. In the reflection phase, students present their ideas and prototypes to members of different disciplines who serve as an interdisciplinary panel to make suggestions and improvements.

« 36 » Once the digital prototype has been agreed upon, the students begin the manufacturing process that produces a buoy. Added to the 2D and 3D design actions described in the creative experience flow, manufacturing with the CNC router and thermoforming technologies appears to continue with the project. This aspect is relevant to understanding the reconfiguration of 2D and 3D design skills with pencil, paper and computer, in new manufacturing skills that involve kinesthetic knowledge of different types of materials, machine programming, manual cutting skills and molds. The challenge that was presented to them to decide on the material to use, consisted in choosing a structure that can house mobile remote sensing devices and at the same time has good buoyancy. For this, the students explored and tested different materials until they reached the high-density expanded polystyrene. This itinerant process of thoughts through different materials and technologies, allowed them to have multiple relevant possibilities to intervene and make a better decision. This sensorimotor feedback loop gave consistency to the ideas as the ontology grew with practice. Figure 1g and 1h show the students cutting some pieces and manufacturing the prototypes with the CNC router machine. Subsequently, and given the need to protect the expanded polystyrene and promote water resistance, the students made a mold on the same machine, which they then thermoformed to give it a plastic shape.

« 37 » Finally, in the phase of showing and narrating, the students reveal their experiences that range from observing and addressing the problem, design, analog and digital manufacturing of the prototype, through the documentation process. This presentation process, open to other classmates and teachers, favors feedback and critical thinking to achieve the optimal prototype that is proposed as a solution to the problems. Students present their prototypes from the most rudimentary sketches to digital design and fabrication with a high level of complexity and difficulty. Within the framework of a preparatory situation that integrates the STEAM disciplines, students can be seen deploying their skills in electronics, 3D modeling and the use of digital fabrication machines that represent the extension of cognition in different channels of creative experience. Through sensorimotor engagement, the tools used serve as a scaffold by illuminating unknown aspects of the artifact under construction, which enrich later forms of making.

« 38 » A relevant aspect of this final methodological step is the critical space in which the prototype is presented, since it contributes to the improvement of the prototype and, therefore, expands new possibilities for the students to continue traveling the creative journey in their STEAM projects. Another fundamental aspect is the opening that is given to the spectrum of art from creativity. Here the students reveal the wandering of becoming in sensorimotor environments in which energy fields and forces imposed by materials intersect when interacting with them. Since they draw, design, cut and manufacture, they reorganize their sensorimotor structure to increasingly challenging levels of engagement. Likewise, this experience does not happen to the students individually and inside their heads, but in the engagement with extended material and the synergy of co-creation of participatory meaning. In this sense, the dynamics of the creative experience is given by different levels of depth, to the extent that skillful knowledge increases with practice, and the optimal relationship between the body and the environment increases.

« 39 » We allude to an optimal relationship when the sensorimotor commitment makes possible new material possibilities not previously available and which provide performativity to artifacts. The nine images presented as a flow of actions to build the buoy can be synthesized in three facets of the experience that account for creativity, as the intuitive and technical 2D design, 3D modelling and manufacturing with the CNC router and thermoforming technologies. These three facets, (a) 2D design, (b) 3D modelling, and (c) manufacturing (using the CNC router or thermoforming) can be seen as a reconfiguration of sensorimotor engagement that goes from more intuitive and opaque notions to more pristine notions, the product of a history of sensorimotor couplings with materials. This flow of actions that accounts for creativity can be metaphorized as catching a large fish that starts with shallow then deep immersion, translated into the sensorimotor configuration that ranges from pencil and paper skills, computational modelling skills, and manufacturing with cutting technologies with the CNC router and thermoforming machines.

« 40 » In the case of the buoy project, we were able to describe, through ethnographic anecdotal reports, how creativity emerges from the deep experience of sensorimotor engagement when designing, modelling, and manufacturing a buoy that arose as a requirement. The way of catching creativity obeys the synergy of contingent relationships triggered by changes in perception that grant advantages to action and vice versa. For this, STEAM provided an interdisciplinary framework of social and material possibilities. From the above, creativity can be understood not as internal mental processes, but rather as distributed, collaborative, and embodied actions that make it possible to seize and transform artifacts in multiple ways. These artifacts are made possible by the sensorimotor engagement of people, by participating and entangling with different types of materiality. From this entanglement, new ways of perceiving and acting emerge, which give shape to the artifact. In the case of building the buoy, this should not be considered as a product of thought, but as a way of thinking.

« 41 » In the case of science, students explored and understood the physical properties of the buoy structure and electronic board. From technology, they were able to use various tools such as 3D-modelling software, the CNC router and thermoforming. In the case of engineering, they understood and used processes based on the technology and some characteristics of the electronic side, in which the buoy had to house the circuit, be airtight and be autonomous for at least 3 hours. Once all the phases have been passed and taking the group's suggestions, the students implement their project together with the organization, Nawi, that had shown them the problem and challenged their creativity to respond to the requirements. As can be seen in Figure 1i, there is a prototype of the buoy that houses the electronic devices that measure certain aspects of the waves, which are then transmitted through a graphical interface, to be understood in a simple way by the user.

## Conclusion

« 42 » In this article we explore creativity theoretically and supported by examples, in the light of the 4E approach and within the framework of STEAM education. We have examined different perspectives that approach it as a process and a product, generally as something that happens individually and linked to a strong disembodied intellectualism. The literature on creativity has been presented from radical embodied approaches or from the perspective of 4E cognition, which allow us to reconsider cognitivist ascriptions. We note that educational approaches that foster 21st century skills, such as STEAM, take scant consideration of creativity compared to 4E cognition that promotes embodiment, anti-representationalism and situationality.

« 43 » Adopting 4E as an approach provides a broader framework for creativity, because creativity can be understood beyond processes and products, by considering skillful practices that specialize in rich environments of artifacts and tools such as embodied forms, embedded and extended. We consider creativity as a deep experience of making with materials, which emerges dynamically during collaborative practice and whose ontology grows through practice. Our research has led us to believe that studying creativity in the flow of contingent actions that transform and reconfigure new ways of perceiving and acting with the material illuminates unexpected facets of cognition, which open up new ways of perceiving and acting that enrich the prototypes. Adding to the above, the collaborative aspect of co-design and the continuous exchange of ideas favors the construction of participatory meanings that enrich and amplify creativity. This is why the STEAM approach is conceived as a favorable field for the deployment of embodied and enculturated ways of learning by doing, since understanding the environment is nurtured by interdisciplinarity equipped with a systemic curriculum and decentralized teaching that fosters creativity.

« 44 » From our theoretical lens, creativity is not something that is abstracted from the body and the dynamics of perception. On the contrary, creativity is something we do as a result of our experience. This means that the notion of creative experience does justice to a more embodied, enactive, embedded, and extended view of cognition. Since the creator is not thought of as someone with an idea in mind, who then executes it with available materials, we consider creativity outside of the logic of the process and the product. More than a retrospective reading of the product, we ascribe to a constitutive ontology that relieves contingent processes and always goes forward. Based on the above, we use Lynch's (2006) metaphor of catching the big fish to refer to creativity, as living ideas submerged in the flow of actions with materiality. What we denote as the catching of the big fish is just an alternative way of referring to the attempt to catch the emerging creation, through design and prototyping. We assume that deeply immersed in materiality, creativity becomes ideas enacted by contingent movements and extended and embedded between tools and machines.

« 45 » In the example of support that we use to grasp our theoretical ideas, and that we describe in the third person, through an ethnographic anecdotal record, we note that design-engineering students from a PBL methodology, in the framework of STEAM, display their creative experience from challenges that they take from observation and empathy with environmental problems. They do this in an environment provided for the enjoyment of distributed perception, which is a laboratory for digital design and manufacturing, where they find paper, cardboard, electronic boards, CNC router machines, art, 3D modeling and sensorization. In addition, they use this project methodology with a dynamic of four steps that are observe/document/do-reflect/show. These steps shape the creative experience, which we read in the light of Varela, Thompson & Rosch (1991) as "laying down a path in walking," a phrase taken from the poet Antonio Machado to refer to cognition as an experiential becoming of sense making.

« 46 » In the context of our example, in which the students had the task of making an artifact that could house electronic remote sensing plates to measure the quality of water in rivers and wetlands, we noticed that the idea about the shape of the structure began on a piece of napkin. The initial shape, which looked like a funnel, mutated in its complexity and sophistication during the prototyping design and manufacturing process, but it retained much of the initial Gestalt intuition that revealed the outline. This idea, as they drew, gave way to more sophisticated sketches that were guided by the idea of a buoy. From the joint work, and with the buoy idea, they began prototyping from the digital design, in which they reconciled perspectives on the structure, trying to capture or grab the prototype ad hoc to the requirements of the task. Each movement or change in the perspective of the object brought new possibilities for action, which triggered the sensorimotor tendency to optimal balance. The skillful practice, an itinerant, improvisatory design of different prototypes is co-created participatively.

« 47 » This process of co-creation that we identify as accounting for creative experience goes deeper and deeper until it finds the shape of the prototype, through digital design. Once the design of the artifact was resolved, the students had to solve the problem of buoyancy and resilience to environmental conditions that the buoy should have. From a deep exploration with different materials, they found high-density expanded polystyrene and a thermoregulated plastic structure. To account for the creative experience, we noticed that the sensorimotor commitment of the students was expanding and diversifying according to the technologies they used in the different stages of the project. Based on the above, we described three actions or aspects of the experience that were key during the creative experience: 2D design, 3D modeling, and manufacturing with CNC routers and thermoformers. This transition of practical skills was illuminating invisible and opaque facets not previously considered, which enriched new ways of understanding and new bodily, social, and material possibilities for transforming the artifact. The progressive sensorimotor commitment with different technological and social scaffoldings favored the possibility of catching the great fish of creativity. Therefore, the creative experience is generated from contingent interactions and relationships that privilege improvisation over abduction, "assigning primacy to the processes of formation as against their final products, and to the flows and transformations of materials" (Ingold 2010: 92).


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« 48 » Finally, and with the materials and digital design, the students used tools and machines to continue shaping the buoy, through the manufacture of the prototype. Once work was done on the cutting of the expanded polystyrene and the thermoforming of the buoy casing, it was possible to find the prototype that met the conditions to satisfy the requirements. This aspect is important for us to highlight, since the creative experience is not reduced to a finished final product to solve a problem. On the contrary, it continues to be perfectible in the light of what arises in the showing phase of the PBL methodology, in which, going by the opinions of other guests from the STEAM disciplines, changes can be incorporated, and therefore, expand and enrich other possibilities of embodying and extending their thoughts through different materials and technologies. From what is shown in our example that supports our theoretical lens, we celebrate the creative experience inherent in skillful practice embedded and extended in materiality, in which design is never there before the act itself (Ingold 2014).

« 49 » We would like to emphasize that changes in the educational paradigm must go hand in hand with changes in the cognition paradigm. The rise of STEAM as an educational approach in which interdisciplinarity, learning by doing together and the use of technologies stand out, requires the 4E approach to finally free itself from dualistic and cognitivist epistemologies. This is because the 4E approach reaffirms the idea of a cognitive system over the notion of a cognitive process, which contributes to fostering new ways of teaching and learning by doing. In this way, the conventional practices of subtracting the body from the classroom, the instructional asymmetry and the centralization of the educational processes are diluted. Also, as we described in our article, beyond some differences among the four Es, they all share across the board that perception is intrinsically relational and affective, a sensorimotor construction that stages and guides perceptually guided action, through multiple artifacts that amplify and diversify skillful ways of thinking, including creativity, as we have discussed.

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